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6. AUTHOR(S)

David C. Dobson

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Texas A&M Research Foundation
Texas A&M University
Department of Mathematics
College Station, TX 77843-3368

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An optimal design method for low-order periodic dielectric diffractive structures in E-parallel polarization has been developed. A key property of the method is that nonsmooth design profiles present no theoretical or practical difficulties so that manufacturable designs can be achieved. The method is based on an accurate partial differential equation diffraction model. It has been theoretically justified, implemented, and applied to reveal some unexpected high-efficiency diffractive structures for potential use in photonic and micro-optical devices.

Research associated with the development of the method has led to efficient numerical methods for calculating diffraction through grating structures and improved understanding of total variation methods for image processing and inverse problems, and has established the groundwork for three-dimensional design methods.

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Final Technical Report
Air Force Office of Scientific Research Grant F49620-95-1-0497

Optimal Design of Diffractive Optical Structures

Principal Investigator: David C. Dobson
Department of Mathematics
Texas A&M University
College Station, TX 77843-3368

Objectives

The objectives of this project were as follows:

- Investigate and develop new optimal design methods based on full PDE diffraction models, to produce effective, manufacturable diffractive structures.
- Work toward substantial improvements in the computational efficiency of optimal design algorithms, so that highly complex problems and 3D geometries become feasible.
- Carry out mathematical analysis to establish fundamental properties of problems and solutions, and to suggest improved computational techniques.

Status of Effort

A new optimal design method for low-order nonsmooth diffraction grating structures in E-parallel polarization was developed [4, 6]. A key property of the method is that nonsmooth design profiles present no theoretical or practical difficulties so that manufacturable designs can be achieved. The method is based on an accurate partial differential equation diffraction model. The optimal design method finds an interface between two dielectric materials in such a way that the difference between a specified energy and the propagated energy in each diffracted mode is minimized. Total variation constraints are imposed on the interface to ensure that the final design is simple enough to be manufacturable. Through preconditioning of the diffraction problem and the use of an efficient minimization algorithm, the method is fast enough to run interactively on a workstation. It has been theoretically justified, implemented, and applied to reveal some unexpected high-efficiency diffractive structures for potential use in photonic and micro-optical devices. The groundwork for the extension of this method to H-parallel polarization and 3D geometries has been established [1].

Progress in efficient preconditioned finite element methods for diffraction problems made in the course of this project allowed a large computational study to understand the behavior of a proposed micro-electro-mechanical structure (MEMS) for tunable infrared filtering [2, 3]. The problem involved high-contrast conductive media, conical diffraction, resonances, and thousands of runs. The flexibility and robustness of the finite element methods enabled a successful simulation which matched well with experimental data.

Research associated with the development of optimal design techniques has led to improved understanding of total variation methods for image processing [8] and inverse problems [5]. A related investigation of eddy current methods for quantifying flaws in homogeneous metal plates was undertaken [7]. This study yielded a new, relatively stable method for recovering vertically averaged flaw profiles. Potential applications exist for aircraft inspection.

Transitions

The new optimal design technique for diffractive structures and related research has been applied in an industrial setting with researchers at Honeywell Technology Center. Honeywell has used this technology on several Air Force and Department of Defense related projects, including design of sensors for aircraft and development of MEMS-based devices for optical applications.

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